Pre-Dam Removal Geomorphic Monitoring
Penobscot River Restoration Project

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PROJECT OVERVIEW

The Penobscot River Restoration Project seeks to restore 11 species of sea-run fish to the Penobscot River, while maintaining existing power generation. This will be accomplished by removing two dams, the Veazie Dam in Veazie/Eddington and the Great Works Dam in Old Town/Bradley, and upgrading fish passage remaining dams at Milford and West Enfield. Additionally, a fish by-pass will be constructed at the site of the decommissioned Howland Dam. Power generated at the Veazie and Great Works dams will be replaced by modifications to the existing Milford dam and Orono dam and powerhouse. Removal of the Great Works dam is planned for the summer of 2012. Breaching and removal of the Veazie Dam is planned to take place in two parts, during 2013 and 2014. Bypass construction is planned, but not currently scheduled. (pers. comm., Penobscot River Restoration Trust, 2012)

The objective of the pre-dam geomorphic monitoring program is to acquire pre-dam removal baseline conditions within areas affected by the Penobscot River Restoration project, as well as provide the foundation for a monitoring program that can be continued as the dams are removed, and the formerly impounded reaches of the river revert to a free-flowing condition.

The monitoring program was built around a series of 15 monumented cross sections, established throughout the project area. Cross section locations were selected to represent the variety of fluvial geomorphic settings found in the project reach: impoundments; unimpounded, freeflowing reaches, immediately upstream and downstream from existing dams; and the mouths of tributary streams.

Each cross section was located and monumented by personnel from the US Geological Survey office in Augusta, Maine. The depth of channel cross sections was also surveyed by USGS personal, once during the establishment of the cross sections in November, 2009, and 6 months later in May, 2010. The end points of each of these cross sections were used as the locations of seasonal photographic surveys. The vegetation and sediment grain size of the unwetted bank portion of each cross section was also characterized at either end of the monumented cross sections. Sediment grain size within the river channel was determined by collecting quantitative video images across the cross sections, and then analyzing still images extracted at fixed time intervals. Sediment thickness and characteristics along cross sections in the Great Works and Veazie impoundments were determined using seismic reflection profiling and ground-penetrating radar.

A summary of the geomorphic monitoring effort is presented in Tables 1 and 2.

Table 1: Summary of Bathymetry and Photo Surveys

Cross Section	Bathymetry 11/16-20/ 2009	Bathymetry 5/17- 19/2010	Photo 01/28& 2/12/2010	Photo 3/31& 4/2/10	Photo 06/8& 9/10	Photo 08/19 & 20/10	Photo 11/18 & 22/10	Photo 03/16& 17/11	Photo 04/13& 14/11	Photo 08/9& 12/11
PEN 1 (LE & RE)	X	NO SURVEY	X	X	X	X	X	X	X	X
PEN 2 (LE, C, RE)	X	X	X	X	X	X	X	X	X	X
PEN 3 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 4 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 5 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 6 (LE & RE)	X	NO SURVEY	X	X	X	X	X	X	X	X
PEN 7 (LE & RE)	X	NO SURVEY	X	X	X	X	X	X	X	X
PEN 8 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 9 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 10 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 11 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PEN 12 (LE & RE)	NO SURVEY	X	X	X	X	X	X	X	X	X
PEN 13 (LE & RE)	X	X	X	X	X	X	X	X	X	X
MEA1 (LE & RE)	X	X	X	X	X	X	X	X	X	X
BLA1 (LE & RE)	X	X	X	X	X	X	X	X	X	X
PIS1 (LE & RE)	X	X	NO SURVEY	NO SURVEY	X	X	X	X	X	X
PIS1 (MOD)	NO SURVEY	NO SURVEY	X	X	NO SURVEY					
PIS2 (LE, C, RE)	X	X								
PIS3 (LE & RE)	X	X	X	X	X	X	X	X	X	X
OBL1 (RE)	NO SURVEY	NO SURVEY	X	X	X	X	X	X	X	X

Table 2:Summary of Underwater Camera, Bank, and Geophysical Surveys

Cross Section	Underwater Camera Survey	Bank Survey	Geophysical Survey
PEN 1 (LE & RE)	NO SURVEY	09/22/11 09/30/11	NO SURVEY
PEN 2 (LE, C, RE)	08/11/10, (only LE to C) 09/15/10 (LE-C, C-RE)	09/22/11 09/30/11	08/19/11
PEN 3 (LE & RE)	08/11/10	NO SURVEY	08/19/11
PEN 4 (LE & RE)	08/11/10	09/30/11	08/19/11
PEN 5 (LE & RE)	06/27/11	09/30/11	NO SURVEY
PEN 6 (LE & RE)	06/27/11 (unsuccessful) 09/29/11	09/22/11 09/30/11	NO SURVEY
PEN 7 (LE & RE)	06/27/11 (unsuccessful)	09/22/11 09/30/11	NO SURVEY
PEN 8 (LE & RE)	08/11/10	NO SURVEY	07/14/11
PEN 9 (LE & RE)	07/07/10	09/22/11 09/30/11	07/14/11
PEN 10 (LE & RE)	07/07/10 07/25/11	09/22/11 09/30/11	07/14/11
PEN 11 (LE & RE)	07/25/11	09/22/11	07/14/11
PEN 12 (LE & RE)	08/17/11 (unsuccessful) 09/29/11 (unsuccessful)	09/22/11	NO SURVEY
PEN 13 (LE & RE)	NO SURVEY	09/22/11	NO SURVEY
MEA1 (LE & RE)	NO SURVEY	09/30/11	NO SURVEY
BLA1 (LE & RE)	NO SURVEY	09/30/11	NO SURVEY
PIS1 (LE & RE)	08/17/11	09/30/11	NO SURVEY
PIS1 (MOD)	NO SURVEY	NO SURVEY	NO SURVEY
PIS2 (LE, C, RE)	NO SURVEY	NO SURVEY	NO SURVEY
PIS3 (LE & RE)	09/15/10	09/30/11	NO SURVEY
OBL1 (RE)	NO SURVEY	09/22/11 09/30/11	NO SURVEY

STUDY AREA GEOLOGY/GEOMORPHOLOGY

An understanding of the geology and geomorphology of the river is important to the interpretation of the landforms and processes at work within the study area.

The Penobscot River watershed encompasses 24,306 km^2 of central Maine (Figure 1). It is the largest river system in the state, when defined on the basis of drainage area and average discharge (465 m^3/sec) (U.S. Army Corps of Engineers, 1990). The river is more than 250 km long, from the headwaters of either of two major tributaries, the East and West Branches, to its mouth in Penobscot Bay. Originally the watershed was slightly smaller, but construction of a dam in 1840 shifted the drainage of Chamberlain and Telos Lakes from the Allagash/St. John watershed into the East Branch of the Penobscot (Barrows and Babb, 1912). The Penobscot watershed is bounded to the east by that of the St. Croix, and to the west by Moosehead Lake and the Kennebec River watershed. Moosehead Lake has an area of 303 km^2, and is Maine's largest lake. It is located immediately to the south of the West Branch of the Penobscot, and forms the headwaters of the Kennebec River system. Other major tributaries of the Penobscot include the Mattawamkeag, Passadumkeag, and Piscataquis Rivers. The Penobscot River can be divided into four geomorphic divisions: Headwaters, Islands, Rapids, and Tidal Divisions (Figure 2).

The Headwaters Division of the Penobscot River encompasses the area upstream of the confluence of the West Branch and the East Branch at Medway (Figure 2). It is a mountainous, high relief region underlain by igneous and low to medium grade metamorphic rocks of lower Paleozoic age. The most prominent geologic feature is the Katahdin massif, a Devonian-age granite (Osberg et al., 1985). Exposed rock surfaces are common at higher elevations, but topographically lower areas are mantled by till, with outwash deposits concentrated in mountain valleys. A well-developed, north-northwest to southeast trending esker system, with associated subaqueous fan deposits and glaciomarine deltas, heads in this portion of the drainage, and extends through all four divisions (Thompson and Borns 1985). Islands within the headwaters division of the main stem of the river are rare, and are limited to gravel bars formed during high flow events, primarily the spring freshet, or erosional remnants of eskers.

The Island Division of the Penobscot River from Medway to Old Town (Figure 2) is markedly different from that of the upper reaches of the watershed in bedrock geology and, correspondingly, in topography. Fine-grained metamorphic, lower Paleozoic-age rocks outcrop throughout most of this area. These easily eroded rock types form a broad valley, with gentle, rolling topography. Bedrock exposures occur intermittently in the area adjacent to the main stem of the river, and form low relief, polished and striated outcrops and rapids. Both the Howland and West Enfield Dams are constructed on bedrock outcrops, and have extensive headponds that drowned rapids identified in Treat's (1820) survey of the river. In other locations, boulder lags create rapids. Bedrock outcrops, thick deposits of till, or glaciofluvial deposits confine the river in the upper portion of this geomorphic division, creating a straight channel pattern and few islands. South of the juncture of the main stem of the Penobscot River and the Mattawamkeag River, the channel becomes more sinuous, and low, elongate islands are more common. Surficial deposits in this division include esker segments, glacial outwash, till, and modern alluvium. Much of the landscape below 60m in elevation is draped with the glaciomarine Presumpscot Formation (Thompson and Borns, 1985).

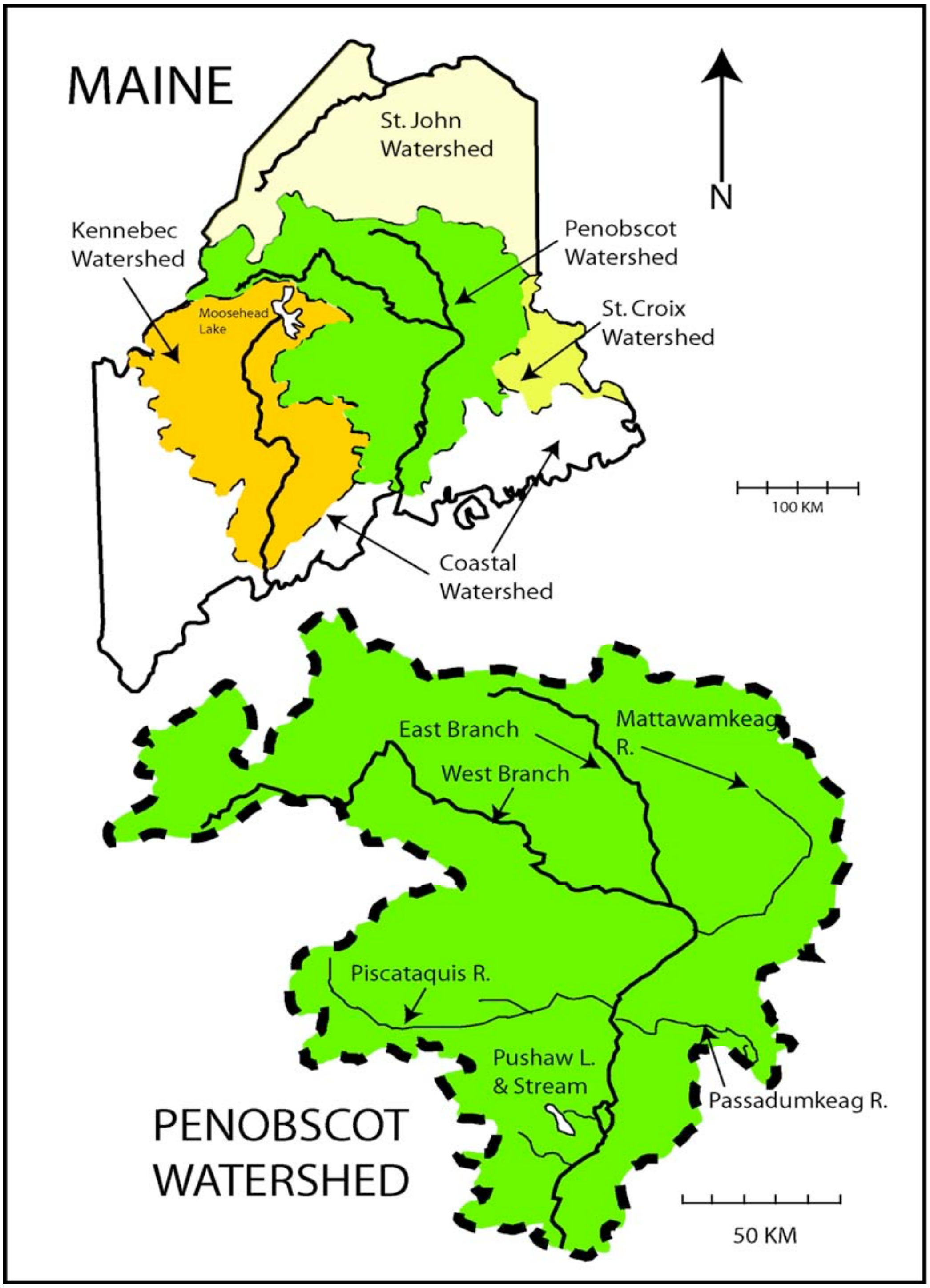


Figure 1: Map of Penobscot Watershed

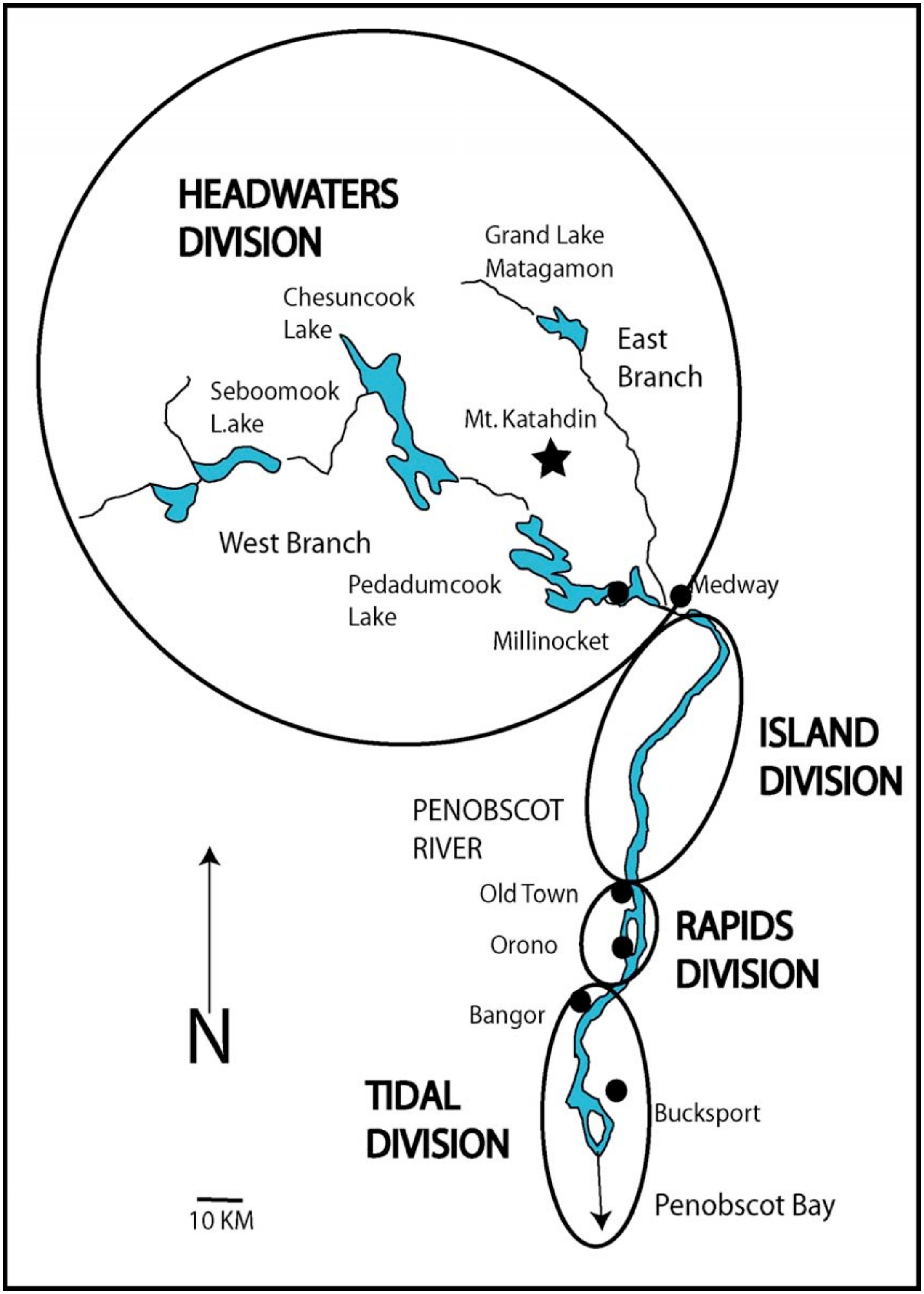


Figure 2: Map of Penobscot River Geomorphic Divisions

The Rapids Division of the Penobscot River extends south from the Old Town/Milford Falls on the Penobscot River to Bangor, and from Gilman Falls on the Stillwater River to Bangor (Figure 2). The Milford Dam is located near the upstream end of this division, although smaller rapids, now inundated by the Milford headpond were mapped between Milford and the mouth of the Sunkhaze Stream by Treat (1820). This section of the river is distinguished by a series of rapids and falls and a lack of depositional islands, and a pronounced increase in gradient through the division. The rapids are created by erosion-resistant, quartz-rich beds in the Paleozoic metamorphic rocks that trend roughly perpendicular to the flow direction of both the Stillwater and the Penobscot Rivers. These features form a sequence of local base levels. The Great Works and Veazie Dams are built on bedrock, creating headponds in what was an area characterized by falls and rapids. Treat's (1820) description of this portion of the river lists 17 rapids and falls, 6 of which are no longer recognizable. The Late Pleistocene Presumpscot Formation mantles much of the landscape. Where it is present, topography is low and rolling, with tributary streams occupying gullied valleys. Till is exposed at the surface at higher elevations, and has a thick, clay-rich matrix as a result of its derivation from fine-grained metamorphic rocks. Esker segments parallel much of the Stillwater River and are present, but more limited, along the main stem of the Penobscot River. Well-developed flights of terraces are present in Old Town, Orono, Bangor, and Brewer.

The head of tide is currently located at Bangor, creating a 40 km long estuary (Figure 2). A pronounced change in the character of the landscape to the south of the Islands Division is the result of a change in underlying bedrock types. South of Bangor, the lower Penobscot flows through a region of low mountains formed by granitic plutons, volcanic rocks, and more resistant high-grade metamorphic rocks. Bedrock cliffs confine the river in several locations. Bluffs composed of till, glaciomarine and glaciofluvial deposits are common. Rapids and falls are absent, giving the river a more mature appearance, as contrasted with the youthful setting upstream. Fringing salt marshes are developed in the mouths of tributaries and small indentations in the shoreline. A large salt marsh is present along the South Branch of the Marsh River, to the west of the main stem of the Penobscot near Bucksport. Immediately south of Bucksport, the river divides into the main channel and an eastern channel to flow around Verona Island. Although mantled with glacial deposits, Verona Island is bedrock-cored and has primarily rocky banks. The divided channel rejoins south of Verona Island and continues south where the river widens dramatically, forming Penobscot Bay.

While underlying bedrock and surfical geology have largely shaped the channel of the Penobscot, its post-glacial history has also influenced the form and characteristics of the present day river. The steep gradient and numerous bedrock rapids and falls of the Rapids Division may be the product of glacial derangement of an older channel of the Penobscot River. A major river, such as the Penobscot would be expected to have a well-developed channel, free from bedrock obstructions. Limited evidence from well and bridge borings suggests a deeper, now filled pre-existing channel may exist to the west of the modern Penobscot in the Rapids Division. Additionally, until approximately 10,000 years ago, the Moosehead Lake drainage was part of the Penobscot watershed (Kelley et al. 2011). Tilting related to isostatic adjustment shifted the outlet of Moosehead Lake into the Kennebec drainage basin, and the upper Penobscot lost approximately 25% of its discharge. As a result, the Penobscot River seen today was one shaped by higher discharges than those generally experienced today.

In summary, the geomorphology of the Penobscot River Restoration area is the result of underlying bedrock geology and a variety of surficial deposits and post-glacial processes. The river channel within the main stem project area is characterized by rapids and falls as the result of glacial derangement of pre-existing drainage patterns. The channel was shaped by higher than present day discharges, prior to the drainage shift of Moosehead Lake. It is these factors and unique history that give this portion of the river its distinctive characteristics.

METHODS

Monumented Cross Section Surveys

The methods employed in the pre-dam removal monitoring program followed the geomorphology-related topics in Collins et al. (2007), and were based on studies largely conducted at a series of monumented cross sections. These cross sections were selected to represent the range of fluvial geomorphic settings in each of the affected reaches of the project area, including impoundments and free-flowing portions of the river, areas immediately upstream and downstream of dams, and within tributary mouths. The endpoints, topography and bathymetry of all cross sections were established and surveyed by USGS survey personnel from the Augusta, Maine office. Terrestrial and shallow portions of the channel were surveyed using a total station. Deeper portions of the survey were investigated using an Acoustic Doppler Current Profiler (ADCP). The GPS coordinates of all monitoring cross section endpoints, as well as location descriptions and access information is presented in Appendix 1.

The Howland study area is located upstream from the proposed Howland fish by-pass, and includes PIS01, PIS01(mod), PIS02, and PIS03 (Figure 3). PIS01(mod) was a temporary, unmonumented cross section. It was used as a photo station only during the first two photographic surveys because PIS01 was inaccessible due to flooding and large blocks of river ice. PIS02 was within the upper portion of the impoundment area, but was not used due to access issues, primarily the midpoint being located on an island. Two additional cross sections used only for photography were located at the Howland I-95 bridge and the Piscataquis River Bridge in the town of Howland (Figure 3). PIS03 was selected as representative of the impoundment conditions. PIS01 was selected to represent free-flowing river conditions.

The main stem study area extends immediately downstream from the Milford dam to the rapids below the Veazie dam, and includes the impoundments of the Great Works and Veazie Dams (Figure 4). PEN01, PEN06, and PEN07 were selected to represent free-flowing, unimpounded portions of the river. PEN02, PEN03, PEN04 and PEN05 represent geomorphic conditions in the Great Works impoundment. PEN05 is located immediately downstream of the Great Works dam. PEN08, PEN09, PEN10, and PEN11 are all located within the Veazie Dam impoundment. PEN12 and PEN13 are located downstream of the Veazie Dam, and are in a free-flowing portion of the river. Two additional monitoring cross sections were located at the mouths of tributary streams. BLA1 is located at the mouth of Blackman stream. MEA1 is located at the mouth of Meadow Brook on the east (right) bank of the Penobscot River.

Monitoring cross section locations were located by Alice R. Kelley, University of Maine, and Mathias Collins, NOAA. Final cross section locations were adjusted to improve access in consultation with personnel from the USGS Augusta, Maine office. Cross section endpoints were monumented by USGS personnel. The following description of the method used is extracted from a report submitted by Pamela J. Lombard of the USGS Maine Water Sciences Center, Augusta Maine. The complete report, which includes detailed descriptions of cross section endpoints and water conditions at the time of the survey is attached to this document as Appendix 2.

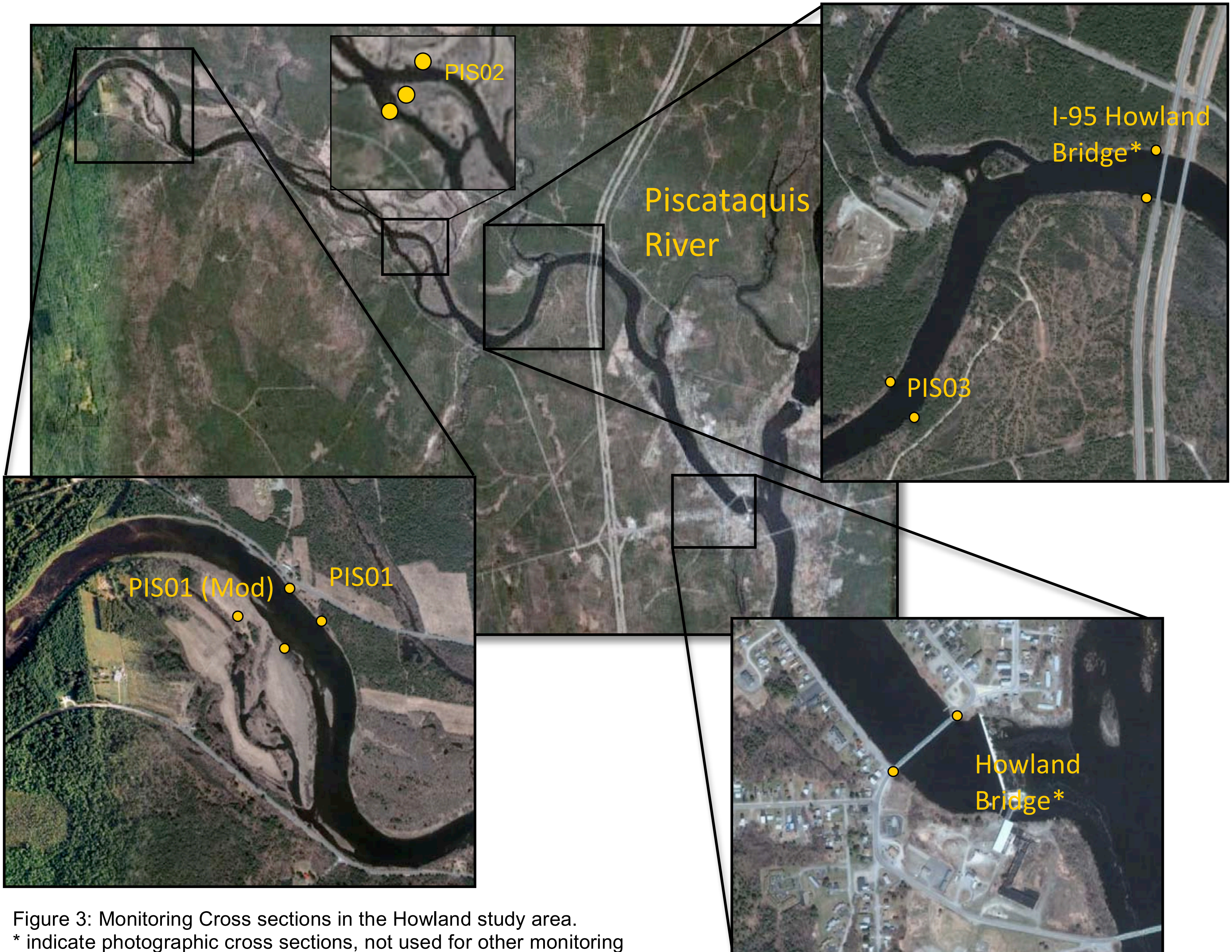


Figure 3: Monitoring Cross sections in the Howland study area.
* indicate photographic cross sections, not used for other monitoring techniques.

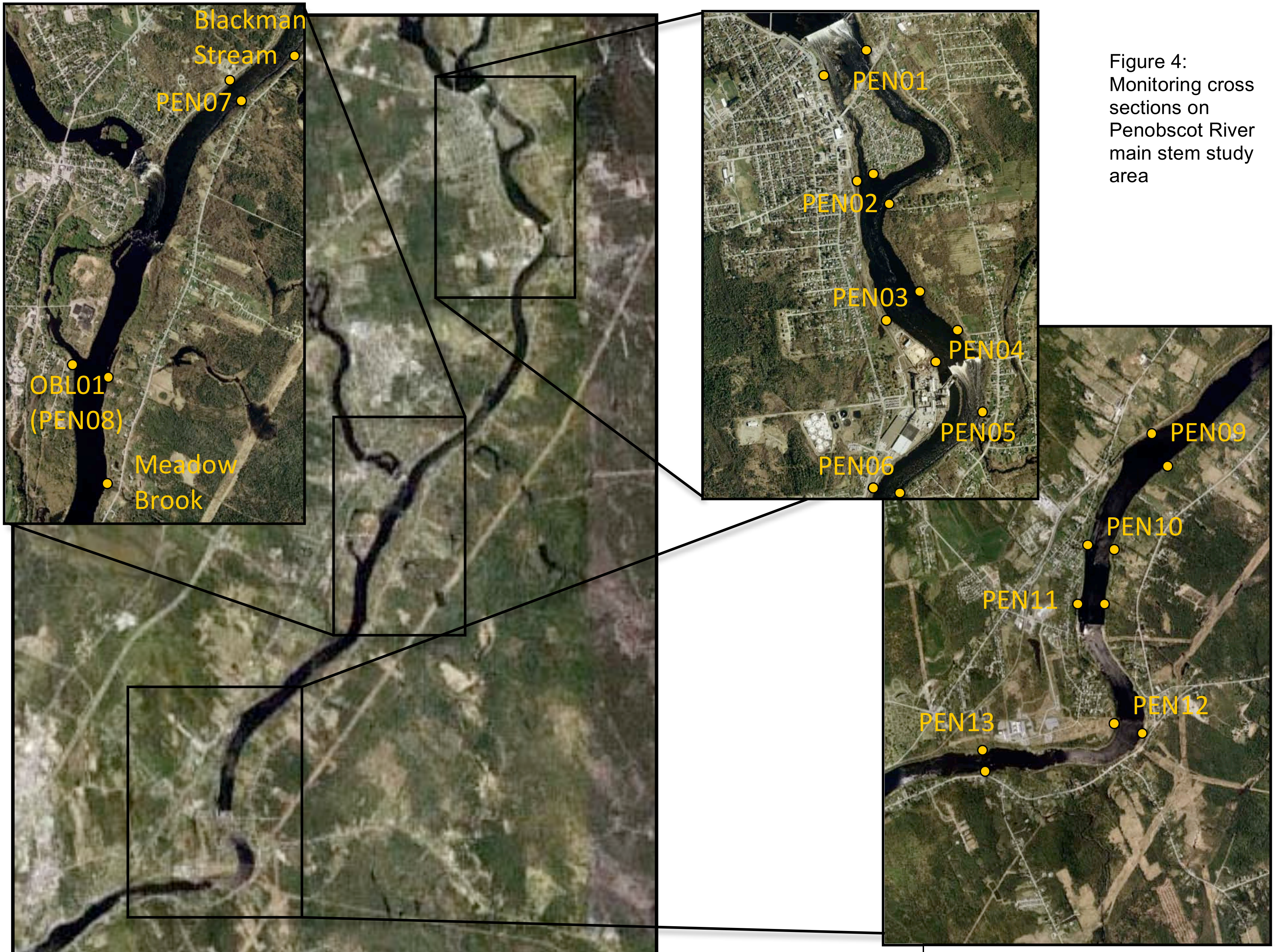


Figure 4: Monitoring cross sections on Penobscot River main stem study area

Most points were originally accessed by boat and descriptions of point locations reflect approach from the water. In some cases, road names were taken from a digital orthophotograph and may or may not match signs on the ground. Cross section endpoints were located using GPS and theodolite surveys

Established benchmark tablets and monuments set in ledge are the most stable monuments (ratings of good to excellent). Manmade structures that extend below the frost line, such as well covers or concrete posts are rated good. Lag bolts in large trees are typically stable in the short term (1-5 years), but not necessarily over the long term (ratings of fair to poor). Large boulders can move with winter ice unless they extend below the frost line (ratings fair to poor). In cases where we did not have a monument rated fair or good within the cross section, we set another monument outside the cross section that can be used as a check, and should be included each time the cross section is surveyed. We were limited in our ability to choose monuments due to the fact that the cross sections needed to be placed in predetermined locations and the monuments needed to be within the cross section. If it is clear that a monument has moved or been destroyed, it should be reset according to the elevation of the monument on the other side of the cross section, or the check monument outside the cross section. In all cases, the elevation from one of the monuments on each cross section was determined with a High Precision Global Positioning System (HPGPS) in 2009 or 2010. For all surveying, the HPGPS latitude, longitude and elevation were considered "true" and all other points were adjusted to it with a total station theodolite. If the difference between the elevations of the monuments shifts more than 0.05 feet, and it is unclear which monument has moved, we recommend using the monument that has the higher stability rating as the stable elevation and to adjust the elevation of the other monument accordingly. In cases where it is impossible to tell which monument may have shifted or in cases where they both have shifted, monuments should be re-GPSed to reestablish vertical control. Table 3 is a presentation of ratings of monument stability and cross section repeatability as determined by the USGS personnel who established the monuments and completed the cross-section surveys.

Channel cross sections were initially surveyed as part of the establishment of the monumented cross sections by USGS personnel on November 16-19, 2009 and resurveyed on May 17-19, 2010 by workers from the same agency. The following procedure is excerpted from a report submitted by Pamela J. Lombard of the USGS Maine Water Sciences Center, Augusta Maine. The complete report, which includes detailed descriptions of cross section surveys and water conditions at the time of the survey is attached to this document as Appendix 2.

Surveys were attempted at monitoring cross section locations, although high flows created hazardous conditions at PEN12 during the 2009 survey. Low flow conditions during the May 2010 survey precluded survey at some cross sections. Table 4 is a compilation of survey dates for each monumented cross section.

More data were collected at the higher flow (2009) by the ADCP at the edges of the cross sections. There are some gaps in 2009 from where the ADCP data ended and the total station data began. At the lower flow (2010) these edge data were collected wading with the total station, and the gaps were filled in. Data collected at different flows can show some differences in station and elevation data along the edges of the cross sections primarily due to the line surveyed. In some cases we accessed the cross section in a slightly different location and that can result in different stationing, especially in the area of steep banks.

Table 3: Ratings of monument stability and cross section repeatability

Monument Ratings			XS Rating	
PEN1LE	PEN1RE		PEN1	
good/fair	good/fair		fair	
PEN2C	PEN2LE	PEN2RE	PEN2L	PEN2R
good	fair	good/fair	good	poor
PEN3LE	PEN3RE		PEN3	
fair	good		good	
PEN4LE	PEN4RE		PEN4	
poor	good		good	
PEN5LE	PEN5RE		PEN5	
good	poor		fair	
PEN6LE	PEN6RE		PEN6	
fair	good		fair/poor	
PEN7LE	PEN7RE	PEN7BM	PEN7	
fair	fair	good	fair/poor	
PEN8LE	PEN8RE		PEN8	
fair	poor		fair	
PEN9LE	PEN9RE		PEN9	
good	fair		good	
PEN10LE	PEN10RE		PEN10	
fair	good		very good	
PEN11LE	PEN11RE		PEN11	
fair	excellent		very good	
PEN12LE	PEN12RE	PEN12BM	PEN12	
fair	fair	good	poor	
PEN13LE	PEN13RE		PEN13	
good	fair		good	
BLALE	BLARE	BLACKBM	BLA	
fair/poor	fair	good	fair	
MEALE	MEARE	MEADERBM	MEA	
fair	fair	good	good	
PIS1LE	PIS1RE		PIS1	
fair/poor	fair		good	
PIS2C	PIS2LE	PIS2RE	PIS2L	PIS2R
poor	fair	fair/poor	fair	good
PIS3LE	PIS3RE		PIS3	
fair	fair/poor		very good	

Table 4: List of cross sections and survey dates

Cross Section	November 16-20, 2009 Survey	May 17-19, 2010 Survey
PEN 1 (LE & RE)	X	NO SURVEY
PEN 2 (LE, C, RE)	X	X
PEN 3 (LE & RE)	X	X
PEN 4 (LE & RE)	X	X
PEN 5 (LE & RE)	X	X
PEN 6 (LE & RE)	X	NO SURVEY
PEN 7 (LE & RE)	X	NO SURVEY
PEN 8 (LE & RE)	X	X
PEN 9 (LE & RE)	X	X
PEN 10 (LE & RE)	X	X
PEN 11 (LE & RE)	X	X
PEN 12 (LE & RE)	NO SURVEY	X
PEN 13 (LE & RE)	X	X
MEA1 (LE & RE)	X	X
BLA1 (LE & RE)	X	X
PIS1 (LE & RE)	X	X
PIS 1 (mod)	NO SURVEY	NO SURVEY
PIS2 (LE, C, RE)	X	X
PIS3 (LE & RE)	X	X

Photography

Images are collected at the endpoints of each cross section and at the additional photo locations seasonally (Table 5). Timing was adjusted to reflect seasonal changes and to accommodate technician availability. Most photo rounds, or sets of photos were acquired on two consecutive days. Occasionally, the survey period was longer, primarily due to inclement weather.

Initially, camera equipment used for the survey was supplied by the field technician conducting the survey. Later surveys used a Nikon D5000 camera with 18 - 55mm Vibration Reduction Lens and a Nikon GP-1 GPS receiver purchased by the Trust for use on this project.

Table 5: Dates of each seasonal photo survey

Photographic Round	Dates
1	01/28&2/12/2010
2	3/31&4/2/2010
3	06/8&9/2010
4	08/19&20/2010
5	11/18&22/2010
6	03/16&17/2011
7	04/13&14/2011
8	08/9&12/2011

Images were collected in three directions at each location:

1. Along the monitoring transect / Across the channel
   Cross-channel images were collected at both 18mm and 55mm lens settings
2. Upstream (Collected at 18mm)
3. Downstream (Collected at 18mm)

GPS locations were collected at each image location using the Nikon GP-1 GPS receiver attachment for the camera (10 m accuracy per manufacturer's manual)

Ancillary Data were recorded, including bearing (direction of each image) and elevation (each image location) and recorded in the photo log for each round of photos. This information was recorded on a standard image logging form along with ancillary notes about weather conditions, time of image acquisition, etc.

The photographic information is archived by photographic round and is designated by sequential number and date. Within the data for each round of photography, images are archived by original images, reduced file-size images, images used in the Google Earth presentation, and the ancillary data.

In an effort to put the photographic survey data in a format that allows direct comparison, photos from each photo survey round were included in a Google Earth .kmz file which links the photos to their geographic location. The procedure for uploading photos and maintaining the Google Earth Site are included in Appendix 3.

<u>Channel Sediment Grain Size Determinations</u>

Channel sediment grain size determinations were based on measurements made on still images extracted from video tows made along monumented cross sections. The video images were collected using a Sea View Underwater camera mounted on an aluminum, lead weighted sled devised by Dr. Daniel Belknap. The sled was designed to hold the camera in a vertical position, at a fixed distance from the river channel bottom, and to have measuring tapes visible within the field of view. The camera was towed across the channel by a boat supplied by USGS. (See Figure 5 a and b) The video feed from the camera was recorded using a Sony Handycam digital video camera recorder. Not all cross sections were examined, due to the challenges of working in shallow, but rapid flow conditions. Tethered boat surveys along the cross sections, but were not used. This decision was made by the USGS personnel who provided boat access for all phases of the study. In the future, this may prove to be a viable method, but will require significant preparation on the banks to safely work in the strong current encountered in many sections of the rive.

Channel grain size determinations were made at the follow cross sections (see Figure 3 and 4 for cross section locations):

PEN02
PEN03
PEN04
PEN05
PEN06
PEN08
PEN09
PEN10
PEN11
PIS01 (Mod)
PIS03

In the lab, videos were edited to remove sections of the record where no forward motion of the tow was accomplished. Loss of forward motion was often caused by snagging on obstructions, such as rocks or submerged logs. A screen shot was selected at the beginning of each tow, and at one minute intervals thereafter. Images were then imported into a graphics program, such as Photoshop. While in the graphics program, the outline of individual clasts greater than very coarse sand or small pebbles were digitized and numbered. A measurement grid was created for the image, using the measuring bars in the image and allowing for camera distortion. The intermediate dimension of each clast was measured and recorded on an Excel spreadsheet. A record of the qualitative analysis of the interstitial material and an estimate of the percentage of interstitial material in the image was also recorded. A detailed procedure is included in Appendix 4.

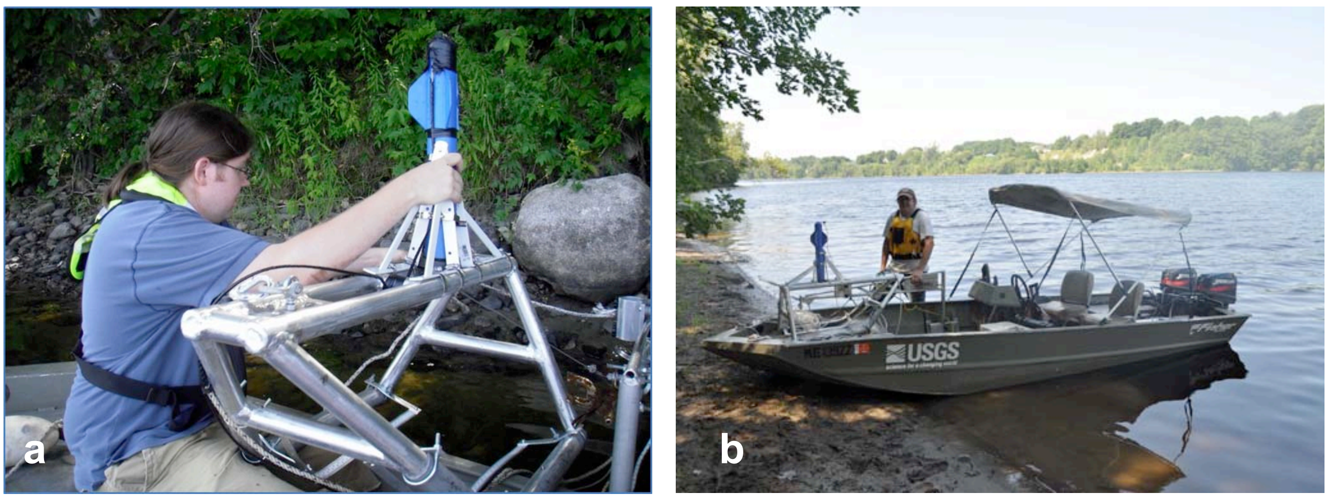


Figure 5a and b: a - Field technician Andrew Heller with camera (blue) mounted on aluminum sled. b – Field technician Andrew Heller with camera and sled on USGS boat.

<u>Channel Bank Grain Size Characterization</u>

The sediment exposed between the monuments and the river water line was examined and characterized one time during the study period. The area surveyed was broken into geomorphically consistent divisions, largely on the basis of similar substrate and slope. Within each division, a .5m x .5m square was placed on the ground and photographic images were collected of the bank sediment within and immediately surrounding the square. Notes and a field sketch were also used to record sediment size class, generalized descriptions of bank sedimentation, and landform characterization.

Analysis of size class data was performed using the same procedure as used for the video tow data. Clasts larger than pebble size were digitized, and the intermediate diameter recorded. Estimates were also made of the percentage of area dominated by finer clast sizes. A detailed procedure is presented in Appendix 5.

<u>Impoundment Sediment Thickness and Characterization</u>

Veazie Impoundment

Geophysical investigation of the Veazie Impoundment was conducted July 14, 2011 with the goal of characterizing impoundment sediment thickness and sediment type. The survey was carried out using a Sweetwater 20' aluminum catamaran with a 50 HP motor, launched from the Orono boat ramp south of Ayers Island. High-resolution bathymetry, differential GPS navigation, and a high-resolution Applied Acoustics Engineering boomer seismic system were used for the geophysical work. Boomer data was collected on the Triton Elics (TEI) topside acquisition system in digital format. Normally this would be linked to DGPS navigation data for geo-referencing, but we experienced problems in this area, and had to rely on the Bathy500DF navigation and other backup navigation. Because of difficulty navigating in the shallow, rock-strewn river we lashed the 20-element hydrophone to the boomer flotation framework. In hindsight, this appears to have created excessive noise, especially when propeller wash was directed at the system. The Bathy500DF precision bathymetric surveyor was mounted to the side rail of the vessel, and the integral DGPS navigation system antenna was emplaced directly on top of the vertical mounting pole for the transducer. The boomer was towed off the starboard stern, steered 1-2 m outside the wake, when possible. The layback between the bathymetric profiler and the boomer was approximately 11 m.

Surveys were conducted along the previously established transects in the Veazie impoundment from the dam up to the rapids at Ayers Island (Figures 6 and 7). Conditions were clear, with nearly calm winds, and a moderate river flow. The most difficult pre-cruise planning was to find a calm weather day with water levels high enough for safety and efficient data collection, but with navigable river currents. Navigation was recorded automatically onto chart paper of the Bathy500DF, and a supplementary paper record was kept by hand at one-minute intervals. Vessel speed was controlled as well as possible to account for currents and turns, attempting to maintain a constant speed-over-ground for the geophysical records, roughly 5 knots. However, post-cruise processing using the navigation was required to adjust for the actual speed variations. Navigation information for this survey is found in Appendix 6-1.

For interpretation of the bathymetric profiles, it is important to note that the depth is relative to 15 cm below the water level. The absolute elevation of the water will vary slightly along the river – see elevation information for the surveyed bank transects for this correction elsewhere in the overall report. The water level at the time of the geophysical survey was leveled to a temporary benchmark (a paint mark at the edge of the launch ramp), and then on 12/16/11 a Total Station leveling transect carried that point to the benchmark on the foundation of the Orono post office – Appendix 6-3. The water level elevation at the launch site was 10.276 m NAVD 88 with an estimated accuracy of a few centimeters.

Raw data from the bathymetric chart printouts were scanned, imported into Canvas 10 graphics, and stretched or shrunk to fit a consistent horizontal scale based on navigation, while maintaining a consistent vertical scale. Water sound velocity was adjusted for freshwater and the temperature using internal Bathy500DF parameters. Subsequently, the bathymetric profile was digitized approximately every 5 m for a numerical record interpretable as x, y, z coordinates.

Seismic profiles were similarly scanned, tied to navigational coordinates, and adjusted to a consistent horizontal scale. The vertical scale is based on a seismic velocity of 1500 m/s in water, but will be higher in sediments. Seismic signal facies are interpreted on the basis of intensity of return (change in materials or density), degree of attenuation, geometry of external reflection, and character of reflections (continuous, discontinuous, chaotic, etc.) (Belknap and Shipp,1991). Profiles are presented as the primary data with georeferencing, and as a line-drawing interpretation where possible. Unfortunately, the noisy data was problematic in several locations

Seismic facies recognized in this survey are extrapolated from previous work in the Gulf of Maine and Maine estuaries (Belknap and Shipp, 1991; Belknap et al., 2002), and specifically tied to this study. The same facies are used in the GPR interpretations of the Great Works impoundment, as follows:

A – Artificial structures, such as historical lumber cribwork or concrete structures. They exhibit abrupt vertical changes and strong reflections, with chaotic or sometimes structured internal reflections. They overlie deeper geological units. Ground truth is provided by the several observations of timber cribwork nearly awash in the survey area, and from the underwater video surveys.

S – Sand and/or muddy sand is interpreted on the basis of consistent parallel stratigraphy, and position only in sheltered areas. S is a rare facies in the survey area.

G – Boulder and cobble gravel is interpreted on the basis of strong reflection with irregular to discontinuous strata, found at the surface over much of the survey area. Cobble gravel is ground-truthed by numerous observations in the underwater video surveys.

T – Till, a glacial sedimentary mixture of gravel, sand and fine sediments, is interpreted below the surficial units from a strong reflection with chaotic internal layers. The distinction between till and overlying gravel is generally speculative. Till is a ubiquitous material on the riverbanks and in general over the region (e.g., Thompson and Borns, 1985).

BR – Bedrock is interpreted on the basis of the deepest strong reflection, and a generally consistent lateral extent. Distinction between bedrock and till is problematical in most places. Bedrock crops out at many spots on the banks and as ledges within the river.

Multiple – seismic waves reflect off the water bottom back to the surface, and return again, giving a multiple reflection that is an exact duplicate of the bottom surface, but distorted such that it is always twice the depth.

GM – Glaciomarine mud, the Presumpscot Formation, might be expected because of its ubiquitous cover on the surrounding landscape (Thompson an Borns, 1985), but it was not recognized in the GPR lines. This is likely because it was completely removed by fluvial erosion during local relative sea-level fall and river incision after glacial retreat (Kelley et al., 2011).

Great Works Impoundment

Geophysical investigation of the Great Works Impoundment was attempted several times in July and August 2011, with equipment and boat motor problems causing delays. The successful survey was conducted August 19, 2011 using a Myers 11' aluminum skiff with a 4 HP motor, towing a 14' plastic canoe, and launched from the south shore of French Island at the foot of Boulanger St. The GPR was chosen for the geophysical work after experience in the Veazie impoundment on 07/14/11 proved problematical in terms of resolution of the boomer seismic device, and difficulty navigating in the shallow, rock-strewn river. The Bathy500DF precision bathymetric surveyor was mounted to the side rail of the skiff, and the integral DGPS navigation system antenna was emplaced directly on top of the vertical mounting pole for the transducer. The PulseEkko100 Ground-Penetrating Radar (GPR) was mounted in the canoe with 100 MHz antennae in line at 1 m spacing. GPR is an electromagnetic signal, so must be distant from large metal objects, and cannot penetrate a metal boat hull. The layback between the bathymetric profiler and the GPR was approximately 8 m.

Surveys were conducted along the previously established transects in the Great Works impoundment from the dam up to the rapids at the toe of the Milford dam (Figure 8). Conditions were clear, with nearly calm winds, and a moderate river flow. The most difficult pre-cruise planning was to find a calm weather day with water levels high enough for safety and efficient data collection, but with navigable river currents. Navigation was recorded automatically onto chart paper of the Bathy500DF, and a supplementary paper record was kept by hand in the skiff at one-minute intervals. A hand log of the time and shot-point numbers for the GPR in the canoe was recorded

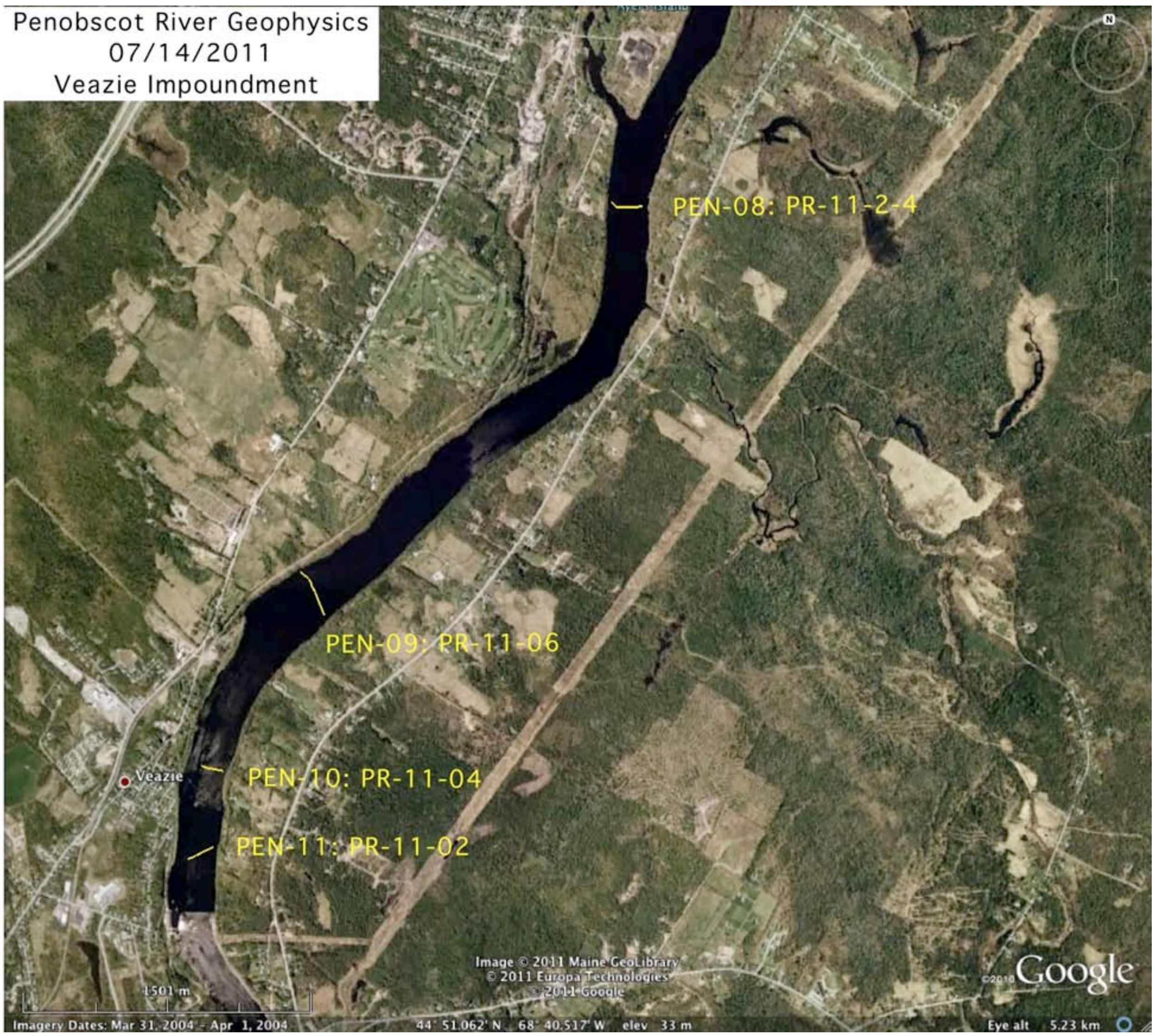


Figure 6 – Geophysical survey 07/14/2011 transect lines in the Veazie impoundment, Penobscot River, Orono.

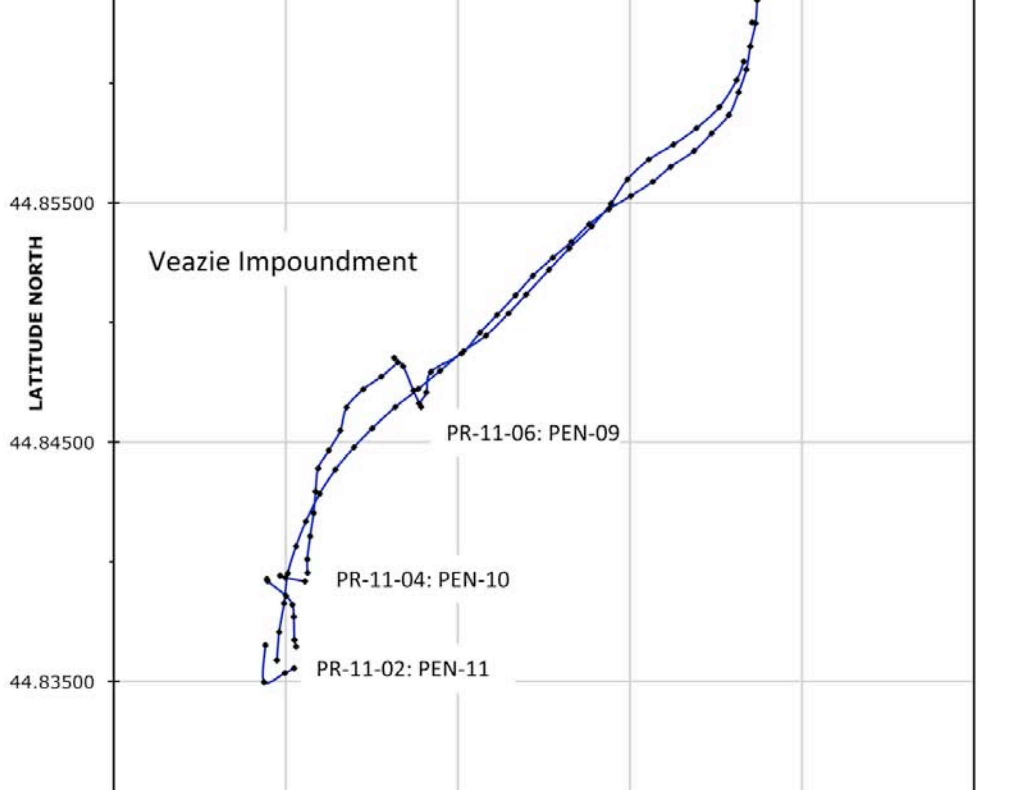


Figure 7 – Map of full geophysical survey lines 07/14/2011 in the Veazie impoundment, Penobscot River, Orono

simultaneously. Vessel speed was controlled as well as possible to account for currents and turns, attempting to maintain a constant speed-over-ground for the geophysical records, roughly 5 knots. However, post-cruise processing using the navigation was required to adjust for the actual speed variations. Navigation information is found in Appendix 6-2.

For interpretation of the bathymetric profiles, it is important to note that the depth is relative to 15 cm below the water level. The absolute elevation of the water will vary slightly along the river – see elevation information for the surveyed bank transects for this correction elsewhere in the overall report. The water level at the time of the geophysical survey was leveled to a temporary benchmark (a paint mark in the parking lot on French Island), and then on 12/16/11 a Total Station leveling transect carried that point to the benchmark on the foundation of St. James' Episcopal Church at the corner of Center and Main Streets in Old Town (Belknap and Heller) – Appendix 6-3. The water level elevation at the launch site was 24.622 m NAVD 88 with an estimated accuracy of a few centimeters.

Raw data from the chart printouts were scanned, imported into Canvas 10 graphics, and stretched or shrunk to fit a consistent horizontal scale based on navigation, while maintaining a consistent vertical scale. Water sound velocity was adjusted for freshwater and the temperature using internal Bathy500DF parameters. Subsequently, the bathymetric profile was digitized approximately every 5 m for a numerical record interpretable as x, y, z coordinates.

GPR profiles were similarly scanned, tied to navigational coordinates, and adjusted to a consistent horizontal scale. The vertical scale is more problematical, as radar velocity varies greatly in different materials. The arbitrary vertical scale is based on a radar velocity of 0.06 m/ns – typical of saturated sand, while that of freshwater is 0.033 m/ns (Sensors and Software, 2001 Table 1, p. 37). Radar signal facies are interpreted on the basis of intensity of return (change in materials or density), degree of attenuation, geometry of external reflection, and character of reflections (continuous, discontinuous, chaotic, etc.). Profiles are presented as the primary data with georeferencing, and as a line-drawing interpretation.

GPR facies were identified using the same abbreviations and descriptions used in the Veazie impoundment survey described above.

RESULTS

Monumented Channel Cross Sections Surveys

Channel cross sections were initially surveyed as part of the establishment of the monumented cross sections by USGS personnel on November 16-19, 2009 and resurveyed on May 17-19, 2010 by workers from the same agency, following the procedure described in Appendix 2. The results of these surveys are presented in Appendix 7, and include excel files of the data, graphic presentations of each cross section, and files required for GIS presentation of the data.

Cross sections were not created for PEN01, PEN06, PEN07 in 2010, due to unfavorable river conditions. PEN12 was not surveyed in 2009 due to dangerous high flow conditions.

Photography

Photographic monitoring at monumented cross sections created a season-by-season view of bank conditions from 2010 through 2011. Presently, this effort is

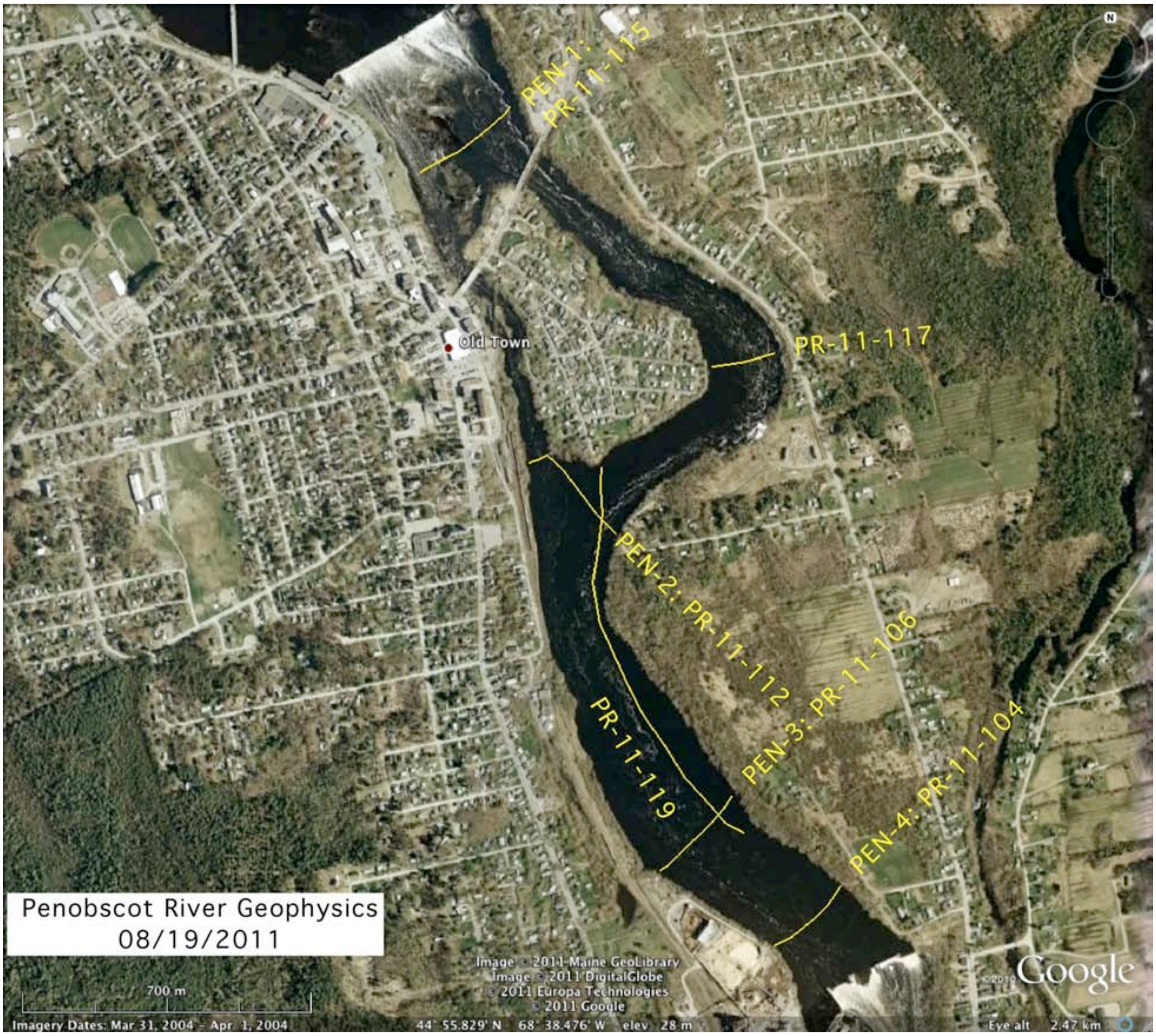


Figure 8 – Geophysical survey 08/19/2011 along transect lines in the Great Works impoundment, Penobscot River, Old Town.

continuing, with images archived in the same formats as those employed for this study, but not included in this report.

As noted in the methods section and in Appendix 3, images were archived as original images and reduced file size images. Photo logs for each round contain ancillary data, including bearing (direction of each image), elevation (each image location), and notes about weather conditions, time of image acquisition, etc.

The results of this effort are presented as Appendix 7, and are organized by photo round. The Google Earth presentation of the data is also included in Appendix 7, as well as an archive of the images used to produce the presentation.

Channel Bed Sediment Grain Size Determinations

Channel sediment grain size determinations were based on measurements made on still images extracted from video tows made along monumented cross sections following the procedure described in Appendix 4. The results of this work is presented in Appendix 9, and includes video, still photos, scales used for determining clast size and an Excel workbook containing the clast size measurements for each still photo.

Channel Bank Grain Size Characterization

The sediment exposed between the monuments and the river water line was examined and characterized one time during the study period, with the procedure used presented in Appendix 5. The results of the the channel bank grain size determinations are presented in Appendix 10, and includes bank survey notes that describe the survey at each location and supporting data for each location.

Impoundment Sediment Thickness and Characterization

Veazie Impoundment

Geophysical data lines are presented in Appendix 11, and are arranged from north to south. Connecting lines and turns are not illustrated here, and exist only as uninterpreted raw data. Bathymetric profiles returned consistent strong surface returns. Unfortunately, as we were just learning the use of this device, the raw data show a strong secondary signal deeper in the record, that is an artifact of the system's display parameters. There is little or no evidence of penetration of the 33 kHz signal into the sediments. Note that all geophysical profiles are presented in landscape aspect at the end of this section. Seismic profiles are also presented in Appendix 11, and appear as the primary data with georeferencing, and as a line-drawing interpretation where possible. Unfortunately, the noisy data was problematical in several locations.

Profile PR-11-2-04 was collected at the outlet of the rapids below Ayers Island in Orono (Figure 5), from west to east, with exposed ledge on its margins. Water depth was between 1-3 meters (Appendix 11-1, 2), and the bottom consisted of cobbles by visual inspection. The seismic data are too noisy for confident interpretation (Appendix 11-3).

Profile PR-11-06 was near the widest part of the river just north of Veazie (Figure 5 for location). The crossing (Appendix 11-3, 4) features a broad, smooth channel consistently near 4 m depth, an a narrower channel reaching 6 m on the NW side. The seismic line (Appendix 11-5) shows a probable thick cover of till over bedrock, overlain by 2 meters of gravel. An important feature of this transect is a fill of gravel and possibly sand up to 5 m thick just SE of the narrow, deep channel. This is interpreted as an incised channel fill left behind by channel migration. This incision also supports the interpretation of thick till in the section.

Profile PR-11-04 was across the channel east of Veazie proper (Appendix 11-6, 7). Shallow ledge outcrops prevented a complete crossing along the transect, and the bathymetry reveals a distinctly narrow channel reaching 7 m depth. The seismic profile (Appendix 11-8) is difficult to confidently interpret because of its shortness and the noisy record. However, there appears to be an appreciable cover of sediment over bedrock. It may be all gravel, as interpreted here, or may also contain a till section, as in profile PR-11-06.

Profile PR-11-02 is the crossing close to the dam warning buoys, at the southern end of the impoundment (Appendix 11-9, 10). This profile covers the broad channel and reaches to 7.5 m water depth, the deepest spot in the survey. A notable feature on this transect is the prominent artificial structure on the bottom, apparently related to the concrete dam-related structures exposed above water level. The seismic stratigraphy (Figure 14) is spotty, suggesting gravel over till (?) and bedrock. We passed the flank of the artificial structure, and there appears to be a drift of finer sediment exposed on the SW flank of the structure at the 60 m distance mark. The sheltering effect of the structure appears to have allowed a sandbank to build up here.

Great Works Impoundment

Geophysical data lines are presented below from north to south, with the exception of the axial profile PR-11-119. Connecting lines and turns are not illustrated here, and exist only as uninterpreted raw data. Bathymetric profiles returned consistent strong surface returns with few cut-outs except on turns, and one instance of a disconnected power cable on PR-11-112. There is little or no evidence of penetration of the 33 kHz signal into the sediments; the deeper, fainter returns are water-bottom multiples. All geophysical profiles are presented in landscape aspect in Appendix 11.

Profile PR-11-115 was collected at the toe of the rapids below the Milford Dam in Old Town (Figure 7), from west to east, and navigating among very shoal bars and channels. Water depth was between 1-2 meters (Appendix 11-13,14), and the bottom consisted of cobbles and boulders. GPR showed little penetration through gravel (Appendix 11-15), with the exception of a somewhat sandier patch in the channel just east of the mid-river islands.

Profile PR-11-117 was from the bend off the eastern end of French Island (Figure 7 for location). The crossing reaches the deepest point of the survey, nearly 7 m at the center of the channel (Appendix 11-16, 17) and features a large, smooth-crested sand bar in the inner part of the bend, on the western shore. The GPR line (Appendix 11-18) illustrates the >3 m thick sand unit on the west, with a small sand unit near the east shore. Most of the remainder of the channel is floored by gravel, with hints of till and bedrock at depth. This is potentially the thickest sedimentary section surveyed, despite the deep channel incision.

Profile PR-11-113 was across the channel at the southwest corner of French Island. Very strong currents and numerous bedrock ledges made data collection difficult, and the navigation is only approximate (Appendix 11-19). The GPR profile (Appendix 11-20) reveals only bedrock with some gravel cover.

Profile PR-11-112 is a continuation of the cross-river transect, from the southwest corner of French island to the Bradley shore (Figure 1 -NW to SE). Despite the data gap, the bathymetry shows rapid depth changes on the NNW end of the line, but a broad channel up to 4 .5 m deep on the SE end (Appendix 11-21, 22). GPR ((Appendix 11-23) reveals that the bathymetric profiler data gap missed a deep narrow channel at the midpoint of the crossing. Sediments are predominantly gravel up to 5 m thick over till and/or bedrock. There is a distinctly lighter return at 5-7 m depth in the sediment at distance mark 130, interpreted as sand below gravel. This would not be unexpected with shifts in channel position, such as if the narrow channel had migrated NW and left a channel-margin deposit behind. Alternatively, this might be a remnant of glaciomarine mud.

Profile PR-11-106 is a direct SW to NE crossing of the straight channel segment east of Old Town (Figure 7 for location). The bathymetry ((Appendix 11-24, 25) is generally smooth and simple, reaching a maximum depth of 4.2 m. However, there are at least 2 and probably 3 or 4 timber cribwork structures over which the profile passed (or flanked). Similar structures were visible just submerged and creating strong eddies in the current. The GPR returns are consistent with structure built on top of the widespread gravel and sand surface across the channel ((Appendix 11-26).

Profile PR-11-104 is the crossing close to the dam warning buoys, at the southern end of the impoundment ((Appendix 11-27, 28). This profile closely resembles PR-11-106, with even more prominent structures on the bottom. The GPR stratigraphy ((Appendix 11-29) is also similar to PR-11-106, with the addition of a drift of finer sediment exposed on the NE flank of the structure at the 60 m distance mark. The sheltering effect of the cribwork appears to have allowed a sandbank to build up here. There is also a sand unit near the northeastern shore.

The finale profile discussed (PR-11-119) was sited with the intention of passing over as many of the submerged cribwork structures as possible, generally from SE to NW parallel to the axis of the river. Appendix 11-30 and 11-31 show the bathymetric profile, which is generally smooth and flat until reaching the flank of the channel at distance mark 50. There are four prominent, large cribwork structures on the profile, and possible another on the flank of the channel. GPR profiling reveals a stratigraphy ((Appendix 11-32) consistent with the cross-section discussed above, with bedrock, till, and a gravel cover. Internal structures appear consistent with the interpretation of framework within the timber cribworks.

DISCUSSION

Monumented Channel Cross Sections

Channel cross sections were surveyed by USGS personnel on November 16-19, 2009 and resurveyed on May 17-19, 2010 by workers from the same agency. Repeat cross section in the Veazie Impoundment (PEN09, PEN10, and PEN11) showed very little variation in channel morphology from the 2009 to 2010 surveys (Figure 9). Other repeated cross sections showed more variation between to two surveys, but changes were not consistent, showing additions or subtractions to channel elevation, and varied less than 3 feet. Without continued surveys of this type, it is not possible to know if these changes are annual changes related to river flow, or an artifact of slight variations in the cross section path across that resulted in surveying slightly different portions of the channel (Figure 10).

In portions of the channel characterized by large boulders and accumulation of logs and debris, a 2-3 foot elevation change could be the result of moving to one side of the other previous survey path and encountering or not encountering a previously surveyed obstruction. A QAQC profile of PEN12 showed variations in channel elevations of up to 2 feet on repeated surveys, when the surveys were done the same day, and the boat operator had a good memory of the travel path. Reoccupying the exact same path 18 months after the initial survey would be extremely difficult.

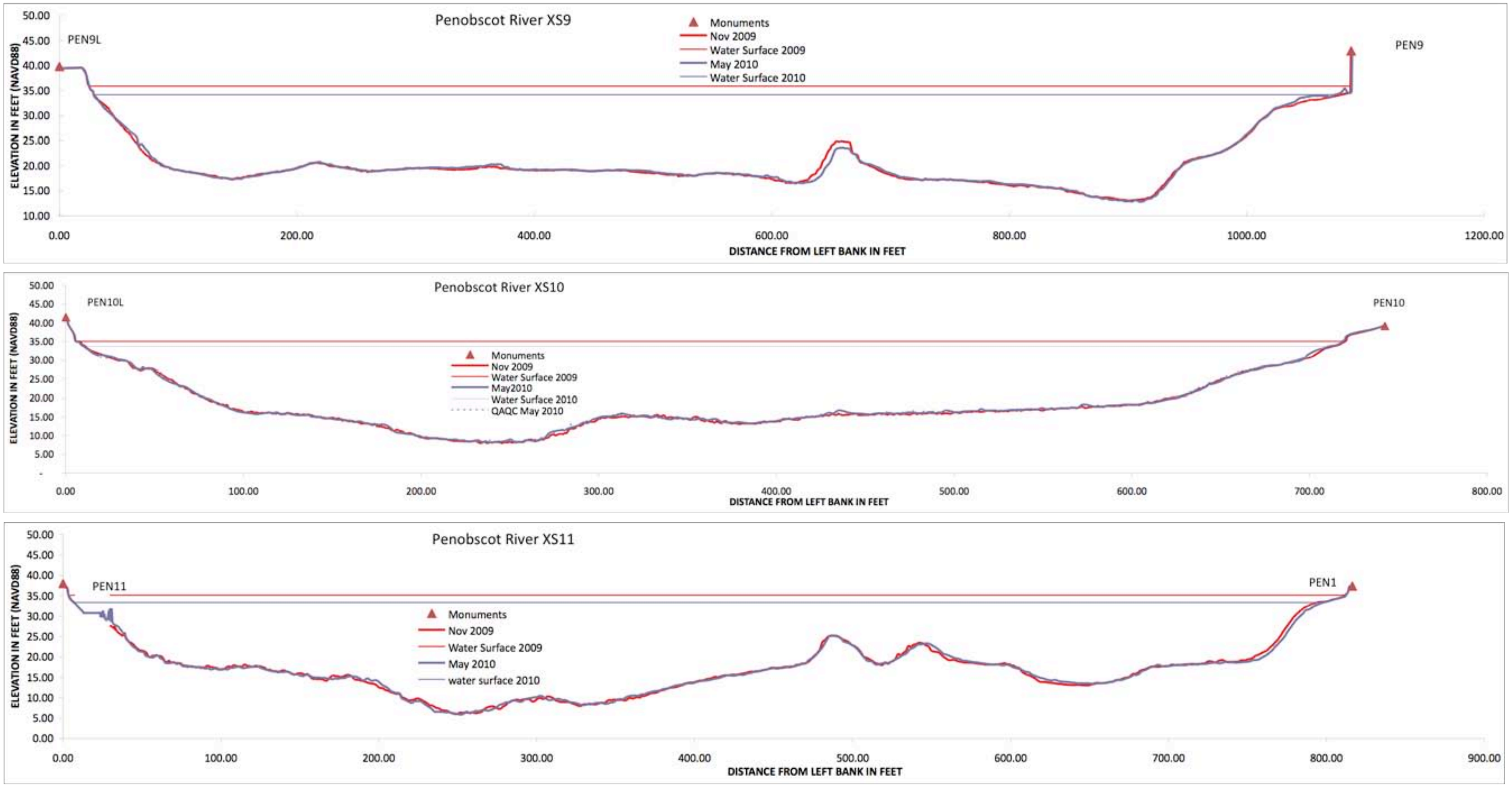


Figure 9: Monumented cross sections Pen 09, 10, 11, showing little variation of cross section morphology in November 2009 and May 2010 surveys.

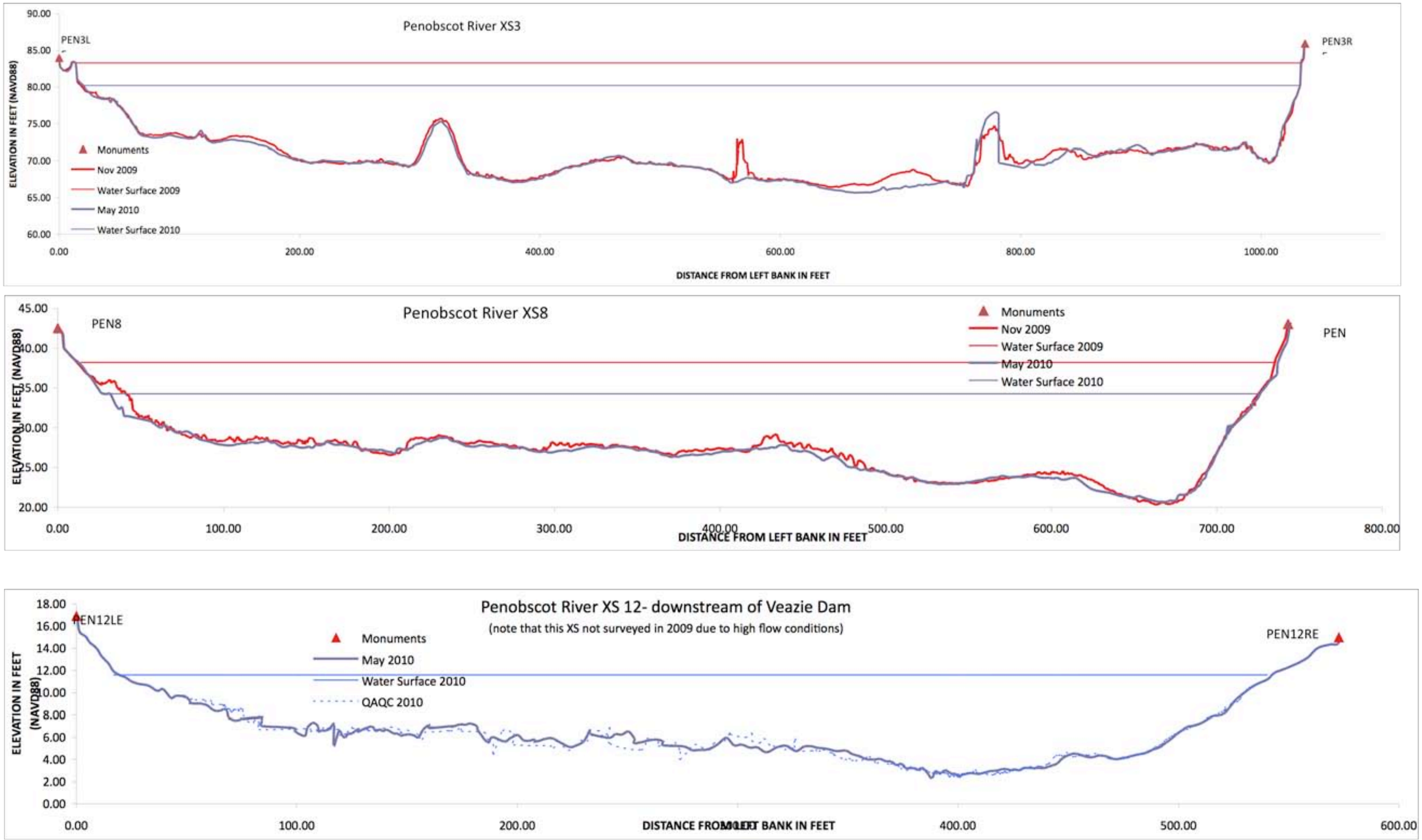


Figure 10: Monumented cross sections PEN 3, 8, and 12 showing vertical variations in channel bed morphology in repeat surveys.

This survey will serve as valuable baseline information if a repeat survey is conducted following dam removal. It is recommended that the surveys be completed along all the monumented cross sections, not just those in the impoundment areas. A complete survey will address the issues of changes in the impoundments, where the most drastic changes are anticipated, as well as possible effects in the previously unimpounded areas.

Photography

Seasonal photographic monitoring provides a baseline of predam conditions and a record of environments for comparison following dam removal. This effort recorded conditions through a range of seasons, and provides reliable evidence for post-dam comparisons, in contrast to anecdotal or infrequent, historical photos. The inclusion of the photographs into the Google Earth framework allows easy comparison of images at a given location through time, and an uncomplicated method to move between data sites for comparison. See Figure 11 for an example of photographic monitoring at one cross section. This is a particularly powerful tool in establishing baseline conditions at specific locations within the study reach. The continuation of this effort through and following dam removal at the Great Works and Veazie dams will provide a record of river environment changes related to dam removal and natural events.

This approach is an economical way to create a long record of images acquired at the same location through a variety of seasons, with the attendant changes in river flow conditions and natural, weather driven phenomena. Data acquisition required two days of field time for two field technicians. Downloading, archiving, and manipulating the data for Google Earth requires approximately 3-4 days effort of technician time for each series of photos. The economical advantage of the method also means that this technique provides “snapshots” of stability or change, rather than characterizing changes along the entire reach, as opposed to the more expensive approach of repeated aerial surveys. Because the Penobscot is a large river (over 250 m wide in many locations in the study area), photos taken from one side to the other may lack detail. In order to better record bank conditions at each location, it is suggested that photo monitoring include images of each bank during each photographic session.

Channel Bed Sediment Grain Size Determinations

The grain size of sediment trapped behind dams in impoundments is a concern when considering dam removal. Accumulations of fine-grained sediment create a supply of easily mobilized material that can be transported by the higher velocity conditions created by a dam breach. This material can be detrimental to fauna and flora in the lower reaches of the river. While anecdotal evidence (Reardon, pers. commun. 2007) and direct surveys by CR Environmental (2008) suggested that the Great Works and Veazie impoundments were characterized by coarse-grained sediment, no quantitative evidence of grain size was available.

The sled used in this study was specially designed by Dr. Daniel Belknap to hold the underwater camera in a fixed position and address the difficult task of quantifying grain size along an entire cross section of a river channel. Data collection was difficult and was hampered by obstructions on the bottom of the channel (boulders and submerged logs), water levels too low for boat operation but too high for wading, and high flow conditions. In spite of these challenges, data was collected for 11 of the

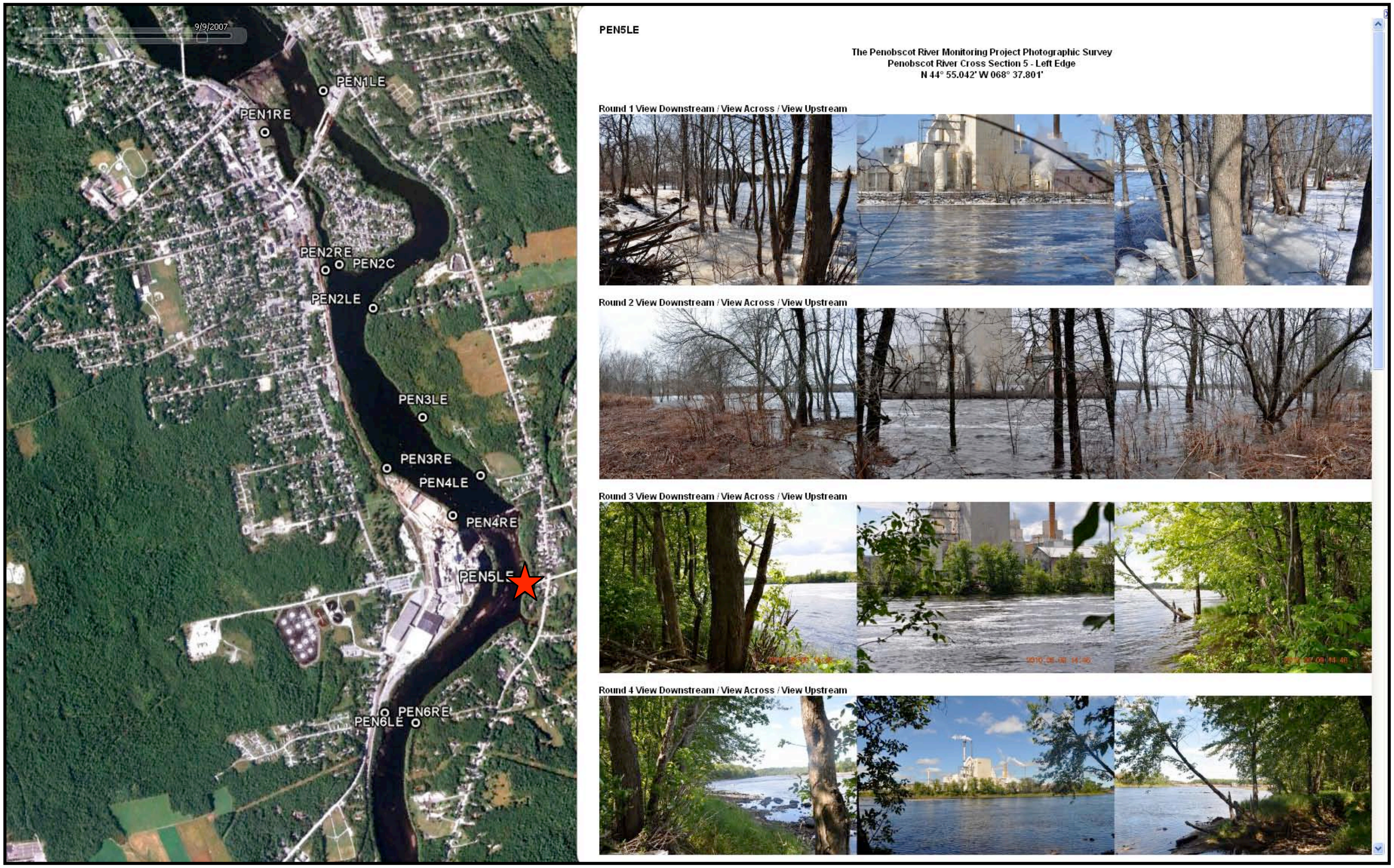


Figure 11: Example of Google Earth presentation of photographic surveys at monumented cross section PEN05LE

monumented cross sections, and showed that the channel bottom was dominated by coarse clasts (mean = 4.9 cm) with a sand or silt matrix. Fine-grained deposits, when encountered, were associated with channel banks. While this information does not characterize the entirety of the river channel, it suggests that coarse clasts with a fine-grained matrix is the dominant channel environment in examined area, with the exception of locations immediately adjacent to channel-side sand deposits, such as eskers. Figure 12 shows a representative image of a still image from the channel bed of monumented cross section PEN 8 with the measuring grid overlain on the image and the location of clast diameter measurements. While the measuring scale in this image is washed out, the camera distance from the scale remained at a fixed distance for the entire survey, allowing use of a clear view of the scale to be applied to all images from the same survey. The accompanying Table 6 presents the clast sizes measured at that location. Table 7 contains the image description notes for the image.

Figure 12: Still image extracted from video camera tow on left (PEN 4, 8th minute). Measuring grid and locations of clast measurement on right.

Looking ahead to possible post dam monitoring, it will be necessary to partially modify this approach. Dam removal and draining of the impoundments will create shallow channels with potentially high velocity flow that will not be accessible by boat. Wading with the camera sled at lower flows may be possible in some parts of the channel, but may be dangerous in deeper sections. A cabled sled tow arrangement may be required if flows are too fast for wading. Discussions with workers seeking to accomplish the same task in other large rivers suggests that this important parameter is difficult to measure, and is a current focus of research (Smith, pers. comm., 2012).

<u>Channel Bank Grain Size Characterization</u>

The channel bank grain size characterization study creates a baseline for comparison with post dam removal conditions. Channel banks were largely composed of fine-grained material, primarily alluvial sediment, and were often heavily vegetated and steep. Glacially polished and striated bedrock outcrops or boulder lag deposits developed from the erosion of till were noted at the base of several cross sections. Glass and trash on the banks is a safety hazard in several locations.

Table 6: Clast measurements for Pen 8, 8th minute frame.

Clast	Intermediate Diameter (cm)	Notes
A		Clast extends out of the field of view.
B	6.3	Clast extends out of the field of view.
D	3	
E		Clast extends out of the field of view.
F	2.1	
G	3.3	
H	3.1	Clast is obscured by clast "G."
I	4	
J	2.1	
K	5.6	
L	2.1	Clast is obscured by clast "K."
M	1.8	
N	5.9	Clast extends out of the field of view. Clast is obscured by clast "A."
O	4.9	
P	3.6	
Q	1.5	Clast is obscured by clast "Y."
R	1.6	
S	1.1	
T	1.3	
U	4.4	
V		Clast extends out of the field of view.
W	3.1	
X	2.4	
Y	16.2	Clast extends out of the field of view.
Z	11.1	Clast extends out of the field of view.
AA		Clast extends out of the field of view.
BB		Clast extends out of the field of view. Clast is obscured by clast "AA."
Mean:	4.113636364	
Standard Deviation:	3.441761633	

Table 7: Image description for Pen 8 cross section, 8th minute frame.

Interstitial Material	% Interstitial Material	% Vegetation	% Wood	Notes
Fine sediment and gravel	25	>1	0	A single piece of vegetal matter at the top of the frame appears to be a dead weed. Fine sediment is sand/silt with a significant proportion (40 - 60%) of coarse gravel. Clast C was removed during review.

Reoccupation of these locations by studies using similar techniques will provide a record of bank stability of change following dam removal. The location of the bedrock or boulder lags at the base of sections will help prevent river erosion of these locations during high flow events. Other geologic processes that will affect channel banks following dam removal will be sheet flow on freshly exposed surfaces, ice action in winter and spring, and ground water seepage along bedrock/sediment interfaces. Figure 13 presents the data from the left edge of BLA1, the Blackman stream monumented cross section.

Impoundment Sediment Thickness and Characterization

Veazie Impoundment

The bathymetry and stratigraphy of the Veazie impoundment reveals a valley incised into bedrock and till, covered by a lag of gravel in most places. There appear to be few fine sediments (sand, mud) in the impoundment basin. It is basically floored by gravel that is unlikely to move except in extreme flow conditions. There also appear to be submerged concrete structures remaining from historic logging control operations or flow-directional features of the dam.

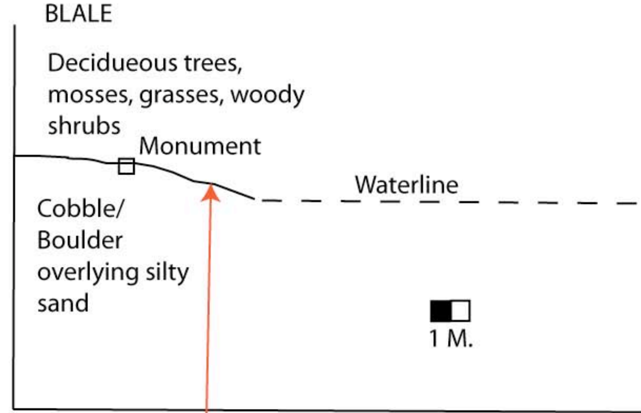
Great Works Impoundment

The bathymetry and stratigraphy of the Great Works impoundment reveals a valley incised into bedrock and till, covered by a lag of gravel in most places. There is a large sand bar on the inside of the French Island bend, and sand bars near shore in several locations. A unique occurrence in this dataset is the sand drift flanking a submerged structure on line PR-11-104. Overall, however, the impoundment is distinctly depauperate with respect to fine sediments, and is basically floored by gravel that is unlikely to move except in extreme flow conditions. The submerged timberwork and perhaps concrete structures remaining from historic logging operations are easily identified, and more-or-less structurally intact features on the river bottom.

BLALE-2

Clast	Intermediate Diameter (cm)	Notes
1	23.5	Clast outside of field of view
2	5.4	Clast outside of field of view
3	1.8	
4	8.5	Clast obscured by clast 5
5	16.1	
6		Clast obscured by clast G
7	1.6	
8	5.6	
9	16.8	
10	5.5	

Mean: 9.4 Standard Deviation 7.2



View of BLALE

Sample BLALE-2

Figure 13: Bank sediment characterization data table, cross section sketch and images.

Summary:

Monumented cross sections were established within the Piscataquis and Penobscot main stem study areas of the Penobscot River Restoration area with the goal of collecting base line data relevant to representative river bank and channel conditions prior to dam removal and fish bypass construction. These locations may also serve as the locations for monitoring studies following river restoration.

Seasonal photographic monitoring provides a direct measure of river and bank conditions throughout the year. Combining these results in a Google Earth database provides a easy to use, location-based method to compare data. Detailed, cross section surveys provided insight into channel morphology change. With only two surveys, it is difficult to separate geomophological changes from variations due to survey path. However, these results provide a useful baseline with which to compare post-dam removal channel morphology. Underwater channel grain size measurements provided a quantitative measure of this parameter, and indicated that, in areas examined, channel substrate was dominated by coarse clasts with fine-grained matrix. Bank grain size study characterized bank morphology and sediment characteristics, and will provie a useful baseline for comparison. Geophysical surveys were used to examine sediment thickness and character within the Veazie and Great Works Impoundments, and further supported the finding of coarse-grained material in the impoundment areas.

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